Pulverised Coal as a Combustible.

By Sir R. A. S. Redmayne, K.C.B.

COAL, which has, ever since the growth of modern industrialism, proved the main source of artificial heat, power, and light in civilised countries, is likely to continue to occupy that position for very many years to come. In some industries it constitutes the chief item of cost in production; in others it is second only to that of labour. Its importance, therefore, as a factor in the cost of living is very great indeed. That the price of coal, at any rate for a long time, will be maintained beyond a pre-war level cannot, I think, be controverted. The higher wage demands of labour incident to the advance in the standard of comfort claimed are not likely to be so abated as to bring wages down to a pre-war position; for the same reason the cost of the materials so largely used in mining—*e.g.* timber, steel, lubricants, and machinery—will remain at a high rate. The chief hope of securing a reduction in the cost of production must lie along the lines of research. Similarly, also, the reduction in the cost of our fuel bill must be sought in economy in use—that is to say, in an endeavour to use efficiently every calorie available in the fuel.

In this connection the use of coal in the form of dust has for some few years been occupying the attention of engineers, particularly during the last five years, and more especially in North America. In the year 1919 the Fuel Research Board published a brochure on the subject, and the May number of the *Bulletin de la Société d'Encouragement pour l'Industrie Nationale* contains a most interesting article by M. Frion entitled "Le Chauffage au Charbon pulvérisé," being a report of the "Commission d'Utilisation des Combustibles," in which it is stated that "le développement devint assez rapide à partir de cette époque, et actuellement les industries du fer et de l'acier emploient environ 3 à 4 millions de tonnes de charbon pulvérisé par an, et les industries du cuivre un tonnage à peu près égal."

The use of coal in the form of dust for raising steam had, from isolated experiments, been known for the last thirty to forty years, but the fact that it is probably the most difficult method of burning coal delayed the development of the practice until means were discovered of surmounting the obstacles in the way of its use. When it is considered that if a cubic inch of coal which has an exposed surface of six square inches is crushed into cubes each of which has a side one-hundredth of an inch in length, and the exposed surface of the crushed coal becomes 600 square inches, the theoretical advantage of burning crushed coal becomes obvious. A more intimate mixing of the fuel and air is rendered possible, and this without using a large excess of air; for example, with an average boiler furnace fitted with mechanical stoking it is considered good working practice under normal conditions if 150 to 200 per cent. of excess air is being admitted to the furnace; on the other hand, under pulverised-fuel firing there is no difficulty in working regularly with not more than 20 to 30 per cent. of excess air.

One of the difficulties which originally lay in the way of the widespread use of pulverised fuel was the heat engendered in the grinding of the coal to the requisite fineness, sometimes resulting in combustion. Again, inasmuch as coal dust cannot be shovelled into and burnt in an ordinary furnace, special burners had to be provided. However, a number of well-tried and standard methods for both the preparation and the burning of the fuel are now in existence, the underlying principle of all of them being the same, though differing in the design of the various parts of the equipment. The coal is dried, pulverised, and the dust, passing to a furnace, is conveyed to a burner, and then, mixed with air, burnt in the form of a jet. Each system has its own peculiar methods of performing these operations, some systems being more suited to certain conditions than others. A point common to all the systems, however, is that of the fineness to which it is necessary to reduce the coal. It has to be ground so fine that the dust will pass through a 100-mesh screen (*i.e.* a screen containing 10,000 apertures to the square inch), and 85 per cent. through a 200-mesh screen (*i.e.* a screen having 40,000 apertures per square inch). In order to effect this the coal must be dried so as not to contain more than 1 per cent. of uncombined moisture, the dryness being necessary from the point of view of manipulation, as the fuel must be capable of being handled without clogging or sticking in the feeding and burning equipment. In the process of drying, care has to be taken against overheating, which may result in loss of volatile hydrocarbons. The cost of securing a higher degree of fineness than that specified above is not justified by the extent of the increased efficiency obtained. On the other hand, practice has shown that if the degree of fineness is much below the standard named above troubles arise due to deposits of ash and slag and from irregular burning.

The separation of the coal ground to suitable fineness from that which is not of sufficient fineness is effected by screening or by air separation. In the latter method a stream of air at constant velocity carries away from the crushed coal particles of a certain definite size and so secures a uniform product, but the use of an air separator requires upwards of 50 per cent. more power to work it than a screen to perform the same amount of useful work, in addition to which the cost of maintenance of the former is heavier, due to high velocity and excessive strains. With air separators the mixture of air and coal dust is carried to a cyclone dust collector, where the stream of air entering the larger volume of the collector is deprived of its velocity and the coal dust drops. With the screen separator the coal is elevated by a bucket elevator and conveyed to the furnace by a screw conveyor.

There are a number of different forms of burning the dust in use, the fuel being driven into the fire-box by means of either fans or compressed air. In one system the air pressure is exerted in the tank, which is in connection with the furnace by means of a pipe, and the dust forced in a stream, unmixed with air, through the pipe to the furnace. In another system the coal dust is drawn from the storage bin as required, mixed with air, and carried in suspension through pipes to the furnace at a velocity of 5000 ft. per minute. Mixing air with the coal dust would appear to increase the liability to explosion. In yet another system the dust from the feed worms is blown into the fire-box, the fuel and air passing as a cloud into the fire-box and being ignited by a piece of waste soaked in paraffin.

One economy incidental to the use of pulverised fuel under boilers has already been mentioned—viz. reduction in the amount of fuel as compared with lump coal to secure a given heat result. Other economies may be mentioned, as follows :—

(*a*) Ability to use low-grade coal.
(*b*) Saving in labour of stoking.
(*c*) Flexibility of the operation, coal-dust firing being almost equal in this respect to oil firing.
(*d*) Elimination of "banking" and easier disposal of ashes.
(*e*) Possibility of safely working the boilers at loads largely in excess of their normal rating.
(*f*) Ease of control of furnace conditions in the case of metallurgical furnaces.

Against these advantages, however, must be ranged the cost of preparing and conveying the pulverised fuel and the interest and depreciation on the capital outlay. These are very variable items, dependent, as they are, on local conditions in respect of labour, power, and fuel, but chiefly on the output per day of the plant. For instance, in the United Kingdom, under present conditions, it is not considered a paying proposition to use pulverised fuel in the case of stationary boilers having a lower fuel consumption than 40 tons of coal per diem. On the other hand, with a fuel consumption of 200 to 300 tons per diem a handsome saving can usually be secured by the replacement of lump coal by pulverised fuel under almost any conditions. As a rough guide it may be taken that with almost any of the well-known standard "systems" the cost of preparing, pulverising, and burning in the form of dust 1 ton of coal, will be about 5*s*. in the case of a plant dealing with 100 tons of coal per diem. Of course, the higher the price of the raw fuel the greater the saving by using it in pulverised form.

Pulverised coal has been successfully applied to almost every kind of heating work, with the possible exceptions of open-hearth steel furnaces, steamships, and such furnaces as glass tanks, where contamination of the charge from particles of ash is to be avoided. The first really successful application of dust-coal fuel was in respect of rotary cement kilns, where the conditions are such that the problem of the disposal of the ash does not exist, and a large combustion volume is available with a free, unobstructed passage for the flame. The next step in its application was in the direction of various types of metallurgical furnaces, more particularly reheating, puddling, and similar furnaces, and complete success has been obtained in most cases.

The case of stationary steam boilers of the water-tube type has been found more difficult of treatment. In the early stages of the adaptation of coal dust to firing, considerable trouble was experienced from the ash and the rapid wear of the furnace lining and from imperfect combustion. Experience has shown the way of avoiding these troubles, and it is now a fact that pulverised fuel can with complete and permanent success be applied in raising steam from any type of tube boiler. In the case, however, of the cylindrical internal flue type of boiler—as, for example, the Lancashire boiler—the process of dust firing has not, so far, proved successful under continuous operation; but, seeing that firing with "straight" oil and with "colloidal" fuel has succeeded in this type, there seems no reason why the problem should not in time be solved in respect of coal-dust firing.

Perhaps the most difficult conditions for the successful application of pulverised fuel were those in respect of locomotives, owing to the small combustion area available and the cramped conditions generally; yet recently it has been completely successful, and locomotives equipped with this system of firing are in use in the United States of America. A fact of peculiar importance, as pointing to a means of utilising low-grade fuel, is that on the Brazilian Central Railway some locomotives are being worked with pulverised coal derived from local deposits of inferior quality in place of using high-grade imported lump coal. In England a system for locomotive use has been successfully developed and has been in service for some time with very successful results. Enough has been said to show that the preparation and use of pulverised coal have been brought to a practical and economic stage, and where the conditions are suitable its use constitutes a proposition worthy of the serious attention of large consumers of fuel. To readers who wish to pursue this matter further the perusal is recommended of the report in the *Bulletin* already named, the Report of the Fuel Research Board, and Mr. C. F. Herington's work on "Powdered Coal as a Fuel."

As illustrative of recent developments, two cases may be quoted. One is from the *Bulletin*, in which M. Frion says :—

"Nous ne citerons que l'exemple particulièrement démonstratif de l'installation nouvelle de 50,000 chevaux en cours de montage à la Milwaukee Electric Railway and Lighting Co. destinée à alimenter une centrale de 200,000 kw." At home pulverised coal has recently been applied at the Hammersmith Central Electrical Station.

The advent of a new process in connection with coal dust has resulted in a considerable step forward being made towards the reduction in the extent of the equipment necessary in the preparation and conveyance of coal dust for combustion. This process is that by which the finely divided coal dust is intimately mixed with oil to form what is inaccurately termed a "colloidal" fuel, for *colloidal* it is not. In this process the coal is ground in oil, a mixture resulting which is sufficiently stable for all practical purposes, especially so when the proportion of solid fuel contained therein exceeds 50 per cent.; mixtures of equal quantities of oil and coal have been used after standing three months in barrels without any difficulty having been experienced in regard to sediment.

In the case of the so-called "colloidal" fuel, unless the amount of moisture is very excessive, the coal can be used without having to resort to drying preliminary to crushing, which means a curtailment in the equipment required as compared with the use of simple pulverised fuel. It has a further advantage in respect of transportation and of handling, in that it is a semi-liquid, and can be treated as an oil fuel, after due allowance for its greater viscosity. It is not liable to spontaneous combustion, and is burnt in the same manner as if it were "straight" oil.

The field for the use of "colloidal" fuel is great. The fuel can be employed wherever oil is applicable as a steam raiser. Its wide application will result in a vast saving in the consumption of oil, and its manufacture allows of the useful employment of low-grade coals and of coals deficient, for other purposes, in volatile constituents.

Remarks on Gravitational Relativity.[1]

By SIR OLIVER LODGE, F.R.S.

IV.

WHEN we come to the more general theory, which attends to the acceleration and not merely the velocity of the observer, I find myself in disaccord on some points with many eminent exponents, chiefly in connection with their abolition of the idea of "force," and the consequent replacement of gravitation by a modified geometry; as if the earth's natural motion was in a hypocycloidal sort of spiral, and was not under compulsion by any deflecting force.

A revolt against "force" as a real objective entity was led by that great mathematician and physicist, Prof. Tait of Edinburgh. In the first instance he rebelled against the practice, adopted by text-books of the period, of using the term "accelerative force" instead of "acceleration," and making a muddle of the laws of motion by formulating what they called Law 3 thus:—"When pressure communicates motion to a body the accelerative force varies as the ratio of the pressure to the mass." Then he objected to some of the pedagogic arrow-heads sprinkled on mechanical diagrams, especially the arrow-head representing centrifugal force; since it is obvious that no such force acts on the revolving body. Ultimately Tait or his disciples (W. K. Clifford too, if I remember right, also Mach and Kirchhoff) were prepared to abandon the term force altogether, and to substitute space-rate of change of energy, or time-rate of change of momentum, or mass multiplied by acceleration, as a more real equivalent. Tait even denounced the idea of balanced forces, saying that only their effects were balanced ("Ency. Brit.," 9th ed., art. "Mechanics," §§ 285–300); as if two opposing forces were each producing their proper amount of acceleration, or of momentum, but in opposite directions. Though how this kind of statement could include the production of scalar quantities, like work and energy, is not apparent. The whole idea of "cause" came into disrepute.

Now mass-acceleration truly is a measure of the force which produces it, but that does not mean identity. Reformers spoke sometimes as if they meant identity, and desired to get rid of the term force altogether because it had been so misused. After a lecture by Prof. Tait to the British Association on "Force" (at Glasgow, in the year 1876), Sir Frederick Bramwell amusingly said that in the North of Britain the term meant a waterfall, while in London it meant the police, and that really, after the lecture, he himself scarcely knew exactly what it did mean! In that lecture Tait had dealt pugnaciously with some misuses of the term by Prof. Tyndall and other scientific people; for it is not so long ago that the words *vis* and *Kraft* were used with but little modification or caution for the quite different conception of Energy. "The Persistence of Force" was a phrase frequently employed in philosophic writings. Indeed, an accurate nomenclature has scarcely yet penetrated into common usage; and the result is an unnecessary vagueness about the term, typified by Sir F. Bramwell's more than half serious confession. Centrifugal force, for example, can be treated correctly enough by equating it to the product of inertia and rate of change of velocity, but that does not do away with the force: the force is exerted by the revolving body against its constraints. The word is misleading if thought of, in what was no doubt its original intention, as a radial fly-away tendency; it should connote only

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[1] Continued from p. 785.